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Primary Synchronization Signal in LTE/LTE-Advanced Systems

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Abstract *– The study is aimed at improvement of Primary Synchronization Signal (PSS) detection in synchronization procedure. The proposed algorithm modifies PSS structure in Long Term Evolution / Long Term Evolution - Advanced (LTE/LTE-A) systems and exploits cross correlation properties of Zadoff-Chu sequences in the other way. We focused on FDD duplexing mode in downlink of LTE radio frame with normal cyclic prefixes and also we applied multipath fading channel in the estimations. Simulation results show that when channel experiences noisy environment or low SNR, the algorithm can work better.*

Keywords*: Synchronization; LTE; Zadoff-Chu; Cell search*

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INTRODUCTION

3GPP has developed LTE-Advanced (i.e. 10th release) subsequent to LTE standards (i.e. 8th and 9th releases). This matter could be attributed to the increasing demands on higher data rates. It should also be pointed out that LTE-Advanced is compatible with its primary release. LTE-Advanced will be the leading global 4th Generation standard fulfilling the defined ITU-R requirements on IMT-Advanced such as peak data rates beyond 1 Gbps. LTE-A operates at both paired and unpaired spectrum those are FDD and TDD duplexing regarding the network requirements, FDD can cover larger area and TDD can assign more downlink capacity, in some cases combination of TDD/FDD are being used.

In LTE-Advanced systems air interface is based on OFDMA technology. OFDM systems are sensitive to time and synchronization offsets, hence require accurate synchronization for interference-free data reception. LTE utilizes up to 20 MHz bandwidth, for which it requires a 2048-point FFT. In the case of LTE-Advanced, a bandwidth of 100 MHz requires an FFT of increased size. If we follow the trend in LTE of FFT size versus bandwidth, for 100 MHz, an FFT size of 10240 would be needed. This will directly affect the memory size, and the base-band processing power requirement.

In cellular telecommunication, UE must search a cell and after registration procedure it will be able to communicate with BS and get synchronized with it. Synchronization techniques, especially the design of a synchronization signal for supporting an efficient cell search in a mobile station are the most important key issues in standardization. PSS (Primary Synchronization Signal) and SSS (Secondary Synchronization Signal) are the important signals which are broadcasted in all directions in which the station provides coverage from the cell periodically and they can offer some useful information to user.

Primary synchronization is required when a mobile terminal connects for the first time to a cell or is looking to make cell handover. The primary synchronization detects the base station sector and time offset.

In [1] procedure of primary synchronization for DL of LTE systems have been investigated and two-step validation procedure have been proposed. In [2] with applying some modifications on traditional algorithm by using properties of ZC and PN sequences new algorithms for PSS and SSS have been investigated. Some studies on [3] have been done on synchronization of unequal-length symbols like symbols with the normal CP. Secondary synchronization signal has been improved by a proposed algorithm in [4] by removing additional scrambling sequences and maintaining the same performance. It helps to reduce the complexity of system. A time and frequency synchronization algorithm for downlink of LTE-TDD has been proposed in [5] which uses ML algorithm.

To the best knowledge of authors, literature is poor regarding improvement of PSS detection in synchronization processes. This paper presents a two-step process for PSS (Primary Synchronization Signal) transfer in order to have more accurate synchronization in downlink of LTE-Advanced systems. The utilized duplexing method in this research is FDD. The preferred measurement to have maximum likelihood between PSS in transmitter and receiver equipment would be differentiation of correlation between subsequent signals.

LTE-Advanced Synchronization

Cell search is a basic function in every cellular system which thoroughly MS and network get synchronized in time and frequency. Cell search occurs in case of primary synchronization or connecting to a new neighboring cell [1]. In LTE, radio cell is recognized by cell ID since it is necessary to have different cell IDs in neighboring cells.

There are 504 different cell identifications in LTE, these cell identifications are categorized in 168 cell-identification groups. Every cell identification group has 3 identities.

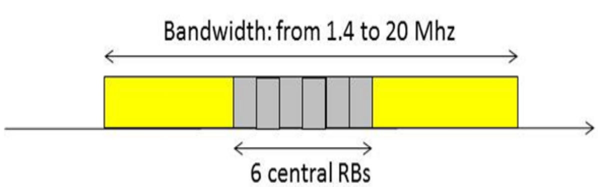
There is a dedicated synchronization channel which carries two synchronization signals those are PSS and SSS which are broadcasted periodically in a cell. These two signals are transmitting 2 times in every 10ms which is LTE frame period. Synchronization will be completed by detecting PSS and SSS. PSS are used to detect $N_{ID}^{(2)}$ which is from 0 to 2 and by using SSS group ID, $N_{ID}^{(1)}$ which is from 0 to 167 will be available. After detection of both PSS and SSS, cell ID will be recognized by the following equations:

$$N_{ID}^{(1)} = 0,1,\ldots,167 \quad (1)$$

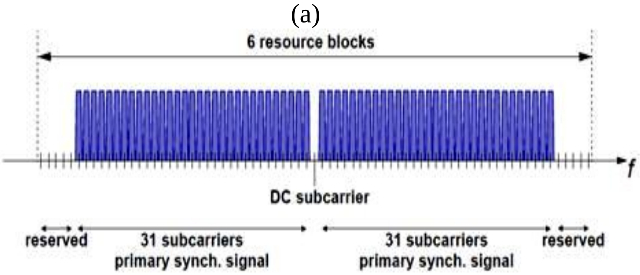
$$N_{ID}^{(2)} = 0,1,2 \quad (2)$$

$$N_{ID}^{(cell)} = 3N_{ID}^{(1)} + N_{ID}^{(2)} \quad (3)$$

In SCH both synchronization signals are mapped to 62 subcarriers which are symmetrically distributed around one DC- subcarrier, that is why cell search is identical for all bandwidth types (Fig.1). Although in LTE there are 72 subcarriers but 10 subcarriers are reserved and just 62 subcarriers have been used.



(a)



(b)

Fig.1 - (a) Resource blocks in different bandwidths and (b) Subcarriers in synchronization signals [7]

PSS signals consist of three orthogonal Zadoff-Chu sequences of length 62 in frequency domain which is generated by Eq.4. Each sequence represents individual sector identification [6].

$$d_u(n) = \begin{cases} e^{-j\frac{\pi u n(n+1)}{63}} & n = 0,1,\ldots,30 \\ e^{-j\frac{\pi u(n+1)(n+2)}{63}} & n = 31,32,\ldots,61 \end{cases} \quad (4)$$

u in the Eq. 4 is representative of root sequence index as detailed in Table 1.

TABLE 1
ROOT SEQUENCE INDEX OF DIFFERENT SECTOR IDENTIFICATIONS

$N_{ID}^{(2)}$	Root Index u
0	25
1	29
2	34

Good auto-correlation property of Zadoff-Chu sequences which represents just one impulse and forced the technology to use it in PSS is depicted in Fig. 2.

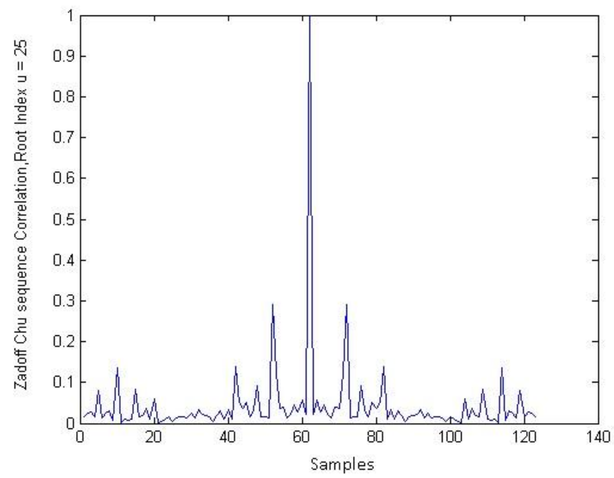


Fig. 2 - ZC sequence correlation

SSS signals consist of a frequency domain sequence with the same length as PSS which is not covered in this paper.

LTE radio frame

One radio frame is composed of 10 sub-frames and each sub-frame is made of 2 slots. Number of symbols per slot could be 6 or 7 depending on cyclic prefix type. If CP is normal, 7 symbols will be positioned in one slot and if the used CP is extended one, there will be 6 symbols in one slot. 1 modulation symbol consists of 6 bits if the modulation is 64-QAM which is used in our discussion. LTE frame which contains PSS signal is shown in Fig. 3.

Wherein PSS is in 6^{th} symbols of 0^{th} and 5^{th} sub-frames, SSS is in 5^{th} symbols of 0^{th} and 5^{th} sub-frames. Mapping of PSS and also SSS over OFDM symbols is different in FDD and TDD systems (This study deals with FDD duplexing mode). The above definition just considers horizontal axis (time domain) in two-dimensional grid of LTE frames which are frequency-time dimensions. In order to have a conceptual view in this issue, we should consider vertical axis which is frequency as well. In this regard, the smallest unit of vertical axis is subcarrier, and the number of subcarriers is different and varies with different LTE bandwidths.

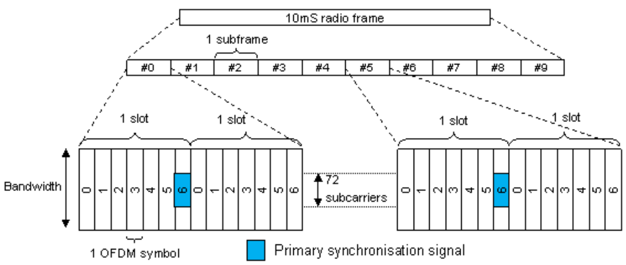


Fig. 3 - LTE frame-FDD [7]

RESULTS AND DISCUSSION

We have used the correlation of received frame and synchronization signal to determine the synchronization position. PSS structure which utilizes Zadoff-Chu sequence in high SNR condition is satisfactory enough to not change its components and also peak points of received and reference signals' correlation diagram are clearly detectable, hence, the problem is in low SNR condition in which due to noisy environment , the number of peak points goes up and it would be difficult to detect them, as a consequence the number of peak points should be decreased (2 peak point in every LTE frame) and by selecting the proper threshold the desired peak points will be detected. For this purpose and since the value of correlation coefficient is between -1 and +1, by changing the structure of PSS to be a combination of PS and –PS, the correlation coefficient between PS and PS would be +1 and between PS and –PS would be -1, the correlation coefficient between any other two parts of signals would be zero as well. Since –PS and PS are consecutive, looking for jumps from -1 to +1 is good index to detect the peak points where differentiation of correlation coefficient would be maximum, and applying this method the number of false detected peaks will be decreased.

As aforementioned we assume that PSS is composed of PS and FS signals. PS comes prior to FS in PSS. These two signals have equal amplitude and are in 180 degrees of phase differentiation. Hence, having different phases is a good indicator to detect synchronization signals. It is obvious that correlation coefficient between PS and itself is 1 and between PS and FS would be -1.

Correlation coefficient between PS and any other part of received signal would be zero. Since the differentiation of two consequent signals those are PS and FS will give a good criterion to have a clear and free of false alarm and misdetections in PSS values. It can be shown that in low SNR conditions by considering the abovementioned method probability of misdetection and false alarm goes down of course the effect of selecting proper threshold should not be underestimated in order to get the desired result.

The well-known multipath fading channel model in LTE/ LTE-A which is EPA as tabulated with profiles in Table 2 is used in this study with maximum Doppler frequency of 5 Hz.

TABLE 2
EXTENDED PEDESTRIAN A MODEL (EPA) [8]

Excess tap delay [ns]	Relative power [dB]
0	0.0
30	-1.0
70	-2.0
90	-3.0
110	-8.0
190	-17.2
410	-20.8

In addition, the number of paths in this study is 2 and modulation type is QAM 64 and the other assumptions are transmission bandwidth which is 1.4 MHz for simplicity and FFT size equal to 128. In order to have more clarifications, the results of research are shown in Fig. 4-7. This point should be added that the proposed algorithm of improving PSS detection is a good solution in low signal to noise ratios.

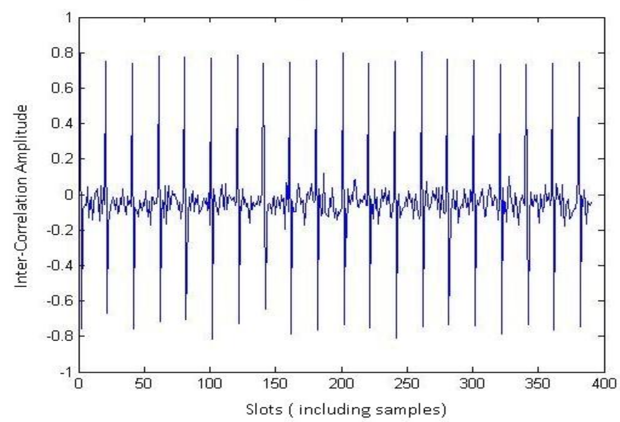


Fig. 4 - Correlation coefficient in high SNR

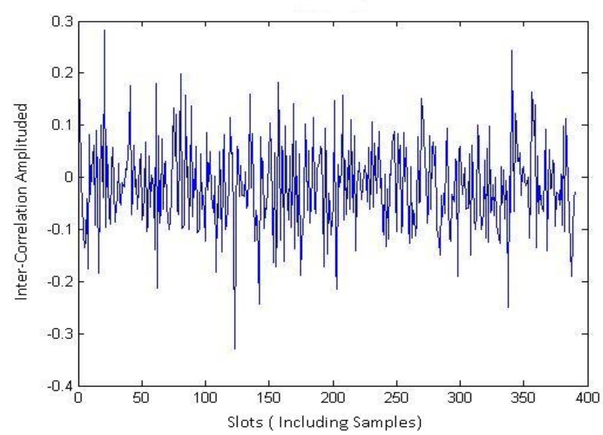


Fig. 5 - Correlation coefficient in low SNR

As it is shown in Figs. 4 and 5, peak detection in high signal to noise ratio is very simple. The challenge is over the second scenario which suffers from low SNR.

Considering abovementioned aspects, instead of using correlation coefficient we used signals differentiation to detect the peaks of synchronization. In order to have a comparison between using combination of PS and FS inside PSS and using pure PS signal the following results have been extracted.

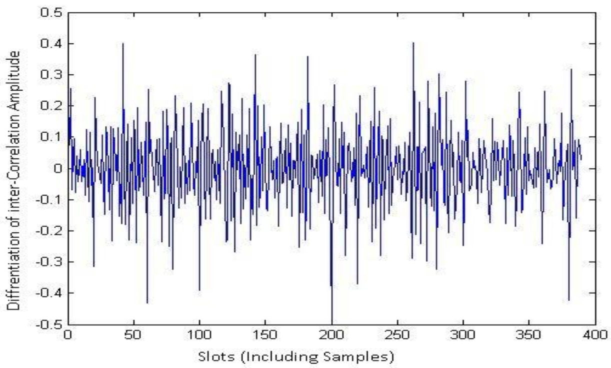


Fig. 6 - Signals differentiations when PSS is composed of just PS signal

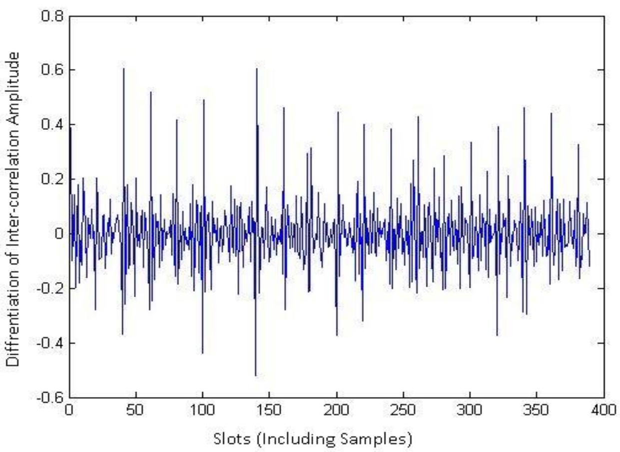


Fig. 7. Signals differentiations when PSS is composed of PS and FS signals

As seen in Figs. 6 and 7, which are simulated in low SNRs, it can be shown that peak detection would be easier when we have PSS which is composed of combination of PS and FS instead of utilizing just PS.

CONCLUSION

In this study we intended to show ideas for increasing the probability of accurate extraction of PSS positions in LTE radio frame in bad SNR situations. By means of simulation results and analysis of comparison between using the proposed algorithm in PSS structure and traditional structure of primary synchronization signals, it is obvious that the discussed method has enhanced the performance of detecting the peaks of differentiation between received and reference signals correlations and make it simple to detect peaks with low error rate. As a future work we will import the effects of MIMO feature in LTE-Advanced systems.

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